AMENDMENTS TO THE SPECIFICATION:

Please replace the specification as filed with the substitute specification attached hereto. A marked-up version of the specification is also attached to delineate each change.

No new matter has been added. It should be noted that the additional figures and description elaborate on the symology that had been previously disclosed in the originally filed specification.

[0011] Prior to this invention, pilots heavily relied on repetitive training to help them with lost visibility outside the cockpit, for example "brownout". In addition to training, helicopter and avionic manufacturers have tried to help pilots effectively deal with brownout. They have proposed several partial solutions, but they have been incomplete or ineffective in dealing with the brownout problem. Some of these attempts include hover displays with velocity and acceleration cues, coupled hover landings using radar altimeter and Doppler coupled autopilots, and FLIR turret vertical lookdown imaging and improved stability augmentation. Full implementation of these individual ideas have not resulted in a full-proof solution to allow a pilot to fly in a degraded visual environment (DVE). None of the proposed prior art solutions have fully addressed the spatial disorientation problem much less allowed a pilot to make a fully stabilized safe landing.

Summary of the Invention

[0012] The present invention recognizes and addresses the foregoing disadvantages, and other prior art methods.

[0013] Accordingly, it is an object of the invention to solve acute DVE problem plaguing helicopter operations , most recently in Iraq and Afghanistan. The US Army, USAF and USMC have experienced accidents attributed to dust blown (or snow-blown) conditions which blind pilots entering a hover.

[0014] Another object of the invention is to provide a DVE solution useable with night vision goggles.

[0015] Still another object of the invention is to provide a DVE solution based on a spectrum of sensor inputs.

[0016] Yet another object of the invention is to provide a DVE system that contains a processor that is functional with any combination of sensors typically found on a helicopter to reduce the customization of the system.

[0017] Yet another object of the invention is to reduce the data workload through automatic assimilation (sensor fusion) of data.

[0018] Another object of the invention is to provide a system for guiding a pilot along an obstacle free path.

[0019] Still another object of the invention is to provide a system that more accurately predicts positions of objects and an aircraft relation thereto.

[0020] These and other objects of the present invention are achieved by providing a DVE solution with augmented visual cues and advanced Fly by Wire (FBW) flight control systems. The system for guiding pilots in DVE situations includes an array of sensors providing inputs to a central processing unit, the CPU, which processes the data from at least two sensors, provides an output to a hover display, and the hover display which guides the pilot to a safe landing.

[0021] Other objects, features and aspects of the present invention are discussed in greater detail below.

[0022] Additional objects and advantages of the invention are set forth in the detailed description herein, or will be apparent to those of ordinary skill in the art.

Description of the Drawings

[0023] Figure 1 is system architecture block diagram of an embodiment of the invention.

[0024] Figure 2 is one embodiment of a hover display.

[0025] Figure 2A is the hover display of Figure 2 displaying symbology illustrating the aircraft translating longitudinally forward at a constant acceleration.

[0026] Figure 2B is the hover display of Figure 2 displaying symbology illustrating the aircraft center of mass is transiting rightward relative to the aircraft longitudinal axis.

[0027] Figure 2C is the hover display of Figure 2 displaying symbology illustrating the aircraft translating longitudinally rearward and decelerating.

[0028] Figure 3A is the hover display of Figure 2 displaying symbology illustrating the aircraft approaching a desired landing point.

[0029] Figure 3B is the hover display of Figure 2 displaying symbology illustrating the aircraft closing over the desired landing point.

[0030] Figure 3C is the hover display of Figure 2 displaying symbology illustrating the aircraft hovering over the desired landing point at 10 feet AGL and beginning a descent.

Detailed Description of the Preferred Embodiments

[0031] It is to be understood by one of ordinary skill in the art that the present discussion is a description of exemplary embodiments only and is not intended as limiting the broader aspects of the present invention. The broader aspects are embodied in the exemplary construction.

[0032] Preferably, the system for flight in DVE comprises a plurality of suites that when interconnected functions to assist a pilot 116 operate a vertical take off and landing (VTOL) aircraft. Typically, the suites incorporated in the DVE system are suites for (FBW) flight control, display, sensors, navigation data fusion and display processing, and control.

[0033] The flight control suite provides a stabilized flight control system. The flight control includes control logic to enable a pilot to command a stabilized flight path, hold hover position and altitude, and execute a vertical landing in zero or near zero visibility. Additionally, variable limits are implemented in the FBW flight control system in response to the height of the aircraft above ground and its rate of descent.

[0034] The display suite can be implemented in a number of ways, however, there are two preferred displays. The first is a head-mounted display with sufficient field of view that provides visually coupled information to the pilot to augment the natural out-the-window view. The information presented on the helmet is stabilized in conformity to overlay the outside scene through the utilization of a head-tracking device. Preferably, the device also permits the pilot to cue the on board systems to points of interest the pilot is viewing in the outside scene. The helmet display may be augmented by other panel-mounted displays to enable transfer of information to the system. The second preferred embodiment is a head up display (HUD) with generally the same information.

[0035] A sensor suite is used to survey the outside scene and to provide environmental information and other information to the pilot to augment visual cues. This environmental information is presented in the form of synthetic imagery which overlays the outside scene, and/or symbology which cues the pilot as to the proper actions to employ to complete a task. The sensors may comprise a radar altimeter, air data system, inertial navigation systems, traffic alert and collision avoidance system, terrain database, global positioning system, microwave radar, 35 GHz wave scanning beam radar. Imagery information that is typically

collected by an imaging system such as a forward looking infrared (FLIR) camera, and video camera.

[0036] A navigation suite communicates with the sensor suite to provide precise navigation information, including groundspeed, ground track, wind direction and speed, location of the landing zone, location of other aircraft in the formation, aircraft performance (power required to hover, power available, etc), vertical velocity, height above ground, etc. The navigation information provided to the pilot is information that cannot normally be gathered by purely visual attentiveness during the approach and landing, especially in DVE conditions.

[0037] A data fusion suite and display processor suite incorporates unique logic and algorithms which fuses together the wide variety of information available from the sensor suites and imaging systems, and displays symbology which facilitates an approach/landing. The display processor suite filters environmental information, imagery information, and navigation information, and converts it into a format for pilot display. This suite fuses sensor information, imagery information, and, if appropriate, creates synthetic imagery and symbology that directs the pilot to conduct tasks in such a way as to complete the approach/landing.

[0038] A control suite includes input/output controls that are employed to enable a pilot to request information from the system, or convey intent, so the processor suite may determine what information is to be presented, at what time, and in what format for the task at hand.

[0039] Referring now to Figure 1, a system architecture diagram of an embodiment of the system 100 to fly in DVE is schematically illustrated in block format. The system 100 includes a data bus 102 with inputs from a variety of sensors, a mission computer or CPU 106, intelligent data fusion processor 110, sensor conditioning and filtering 108, fly by wire (FBW) flight control system 104, and a Forward Looking Infrared System (FLIR) 112.

[0040] The pilotage of the VTOL aircraft is through the FBW system 104. The FBW system 104 preferably has certain inputs in order facilitate pilot control of the aircraft. The first main input is from the data bus 102. The data from the data bus 102 may include air data, GPS information, a radar altimeter, obstacle avoidance equipment, Enhanced Ground Proximity Warning System (EGPWS)/Controlled Flight Into Terrain (CFIT), digital map, and Differential Global Positioning System (DGPS) among others. The data bus 102 data is fed to a mission computer 106, which outputs signals to the FBW system 104 to manipulate the aircraft in close

proximity to terrain, and to a sensor conditioning and filtering system 108 that filters the data to extract particular data signals. The mission computer 106 and the sensor conditioning and filter system 108 provide data to a data fusion processor 110, which analyzes the data and compiles the various data into a combined output. For example, when there is both FLIR and visual imagery data, the data fusion processor 110 combines the imagery information from the FLIR system and visual information from a camera system as well as symbology generated from the environmental information collected by the sensor suite into a single picture displayed in a hover display 114. The hover display 114 may be displayed in a head mounted display (HMD) 120 or on a head's up display.

[0041] Additionally, the data fusion processor 110 provides information to the FBW system 104. The combined environmental information and mission-specific information may be used to automatically manipulate an aircraft such that obstacles are automatically avoided. By direct communication with the FBW system 104. The data fusion processor 110 and the FBW system 104 both provide data so that a display 118 as shown in more detail in Figure 2 may be generated. The display 118 may also be provided for display in the HMD 120.

[0042] While it is typical for attack helicopters to utilize a HMD that incorporated contact analog flight symbology to maintain continuous heads up, eyes out posture, most aircraft continue to use head down displays and/or non-head tracked symbology (HUDs). Therefore, a head down approach to hover and hover display may additionally or alternatively be provided as illustrated.

[0043] The intent of the display 118 is to provide the pilot with precise pilotage cueing in the approach to hover, with reference to aircraft velocity, location relative to the planned landing area, altitude and rate of descent. Most importantly, trend information is provided to assist the pilot in seeing a future state of the aircraft. Overlaid on the trend information is command cueing to indicate what the optimal trend is at the current point in the descent profile. Additionally, the display provides a pilot with visual indicator symbology such that the pilot is aware of unsafe landing areas.

[0044] The symbology provided by display 118 shown in Figure 2 below provides this precise pilotage cueing for approach to hover, with reference to aircraft velocity, location relative to the planned landing point, altitude and rate of ascent/descent information in a single, integrated data set to reduce pilot workload through automatic assimilation (sensor fusion) of

data. That is, the information from the multiple of sensors and FBW system are combined through data fusion and displayed on display 118 in a format which readily improves pilot cuing to a desired landing point through intuitive symbology.

[0045] The display 118 preferably combines distance (relative position between current aircraft position and desired landing point) aircraft velocity (velocity vector) and aircraft acceleration (acceleration ball movement relative velocity vector) information all on one display in a symbology format which radically improves approach to hover. Notably, the acceleration ball is also preferably color coded to provide further indication of acceleration, such as green for below or on acceleration limits, yellow for close to acceleration limits or red for above acceleration limits.

[0046] In Figure 2, the symbology illustrated on the display 118, exemplary illustrates that the aircraft is close to the desired landing point, however it is translating to the right, away from the desired point. The deceleration rate is within tolerance for the current altitude such that the acceleration ball would be green. The velocity trend is displayed by the acceleration ball which moves relative to an end of the velocity vector opposite the aircraft current position point. Here, the acceleration ball is indicating that the aircraft is decelerating as the acceleration ball is on the velocity vector closer to the aircraft current position point. When the velocity vector and acceleration ball are contained within the auto deceleration constraint circle, automatic hover control is preferably initiated by the FBW system.

[0047] The velocity vector, which extends from the current aircraft position point, extends and retracts in proportion to aircraft ground speed. The direction of the vector on the display 118 is equal to the angle between the ground track of the aircraft center of mass and the aircraft centerline. The acceleration ball (small circle in line with the velocity vector) is referenced to the end of the velocity vector and displays the instantaneous acceleration rate of the aircraft, i.e., the first derivative of the velocity vector. With zero acceleration, the acceleration ball remains at rest over the end of the velocity vector (Figure 2A). As the aircraft accelerates, the acceleration ball will displace relative to an end of the velocity vector a distance in proportional to the acceleration. The velocity vector will then extend to meet the acceleration ball as the aircraft velocity increases. The value of acceleration used to calculate the position of the acceleration ball is preferably predictive acceleration which factors in instantaneous acceleration, pilot stick position, and flight control dynamics.

[0048] For example, if the aircraft is flying straight ahead with no disparity between ground track and aircraft centerline, the velocity vector extends forward/longitudinally up from the current aircraft position point (Figure 2A). However, if the aircraft ground track is, for example, accelerating forward and tracking right relative the aircraft centerline due to cross-wind or other disturbance, the velocity vector will be angled to the right (Figure 2B). If, for example, the aircraft is moving rearward and decelerating, the acceleration ball is moving toward the current aircraft center point along the velocity vector which is also retracting in length to indicate decreasing velocity (Figure 2C).

[0049] A rate of ascent/descent altitude trend tape indicates a change in altitude trend which predicts the altitude to be approximately 20 ft Above Ground Level (AGL) several seconds in the future. The altitude trend tape is located adjacent to the current aircraft altitude tape and includes an altitude tick fixed to the end thereof. The tic serves as a visual "pointer" to increase visibility and attract pilot attention. The altitude trend tape indicates an altitude ascent/descent trend, i.e., the first derivative of altitude data to predict a trend in the aircraft's altitude. The altitude trend tape indicates the resultant altitude of the aircraft several seconds in the future. Notably, the altitude trend tape, like the acceleration ball is also preferably color coded to provide further indication of ascent and particularly descent, such as green for below a predetermined descent limit relative to altitude, yellow for being close to the predetermined descent limits and red for being above predetermined descent limits relative to altitude.

[0050] In Figure 2, for example only, the altitude trend tape indicates a decreasing altitude trend indicating that the aircraft will be approximately 10 feet AGL several seconds in the future. A text field at the bottom of the display provides quantitative readout of critical information (current altitude, rate of descent, ground velocity) to increase situation awareness.

[0051] Referring To Figures 3A- 3C, the aircraft is moving forward longitudinally (at 30 knts) but slowing as indicated by the acceleration ball retracting down the velocity vector (Figure 3A). Altitude is also decreasing as indicated by the altitude trend tape. Notably, the display 114 generates symbology to indicate a terrain obstacle such as the displayed power lines. The obstacle location may have been determined by the sensor suite, FLIR system, terrain database, or other source. The data fusion processor 110 positions the obstacle in spatial relationship relative to the current aircraft position such that the pilot can manipulate the aircraft to avoid the obstacle. Preferably, the FBW system will automatically adjust the aircraft flight

path and override the pilot flight commands should the aircraft flight path be directed toward the obstacle.

[0052] In Figure 3B, the aircraft it coming to a hover at 50 ft. AGL over the landing point. The aircraft is still has a slight forward velocity (18 knts) but the aircraft is still decelerating as indicated by the acceleration ball which is retracted from the end of the velocity vector. Note that the velocity vector is shorter in Figure 3B relative to Figure 3A. Notably, as the acceleration ball and the velocity vector are within the auto decel circle, auto hover mode in the FBW system is available and the pilot need only make final adjustments. The aircraft is also still descending but at a lesser rate.

[0053] In Figure 3C, the aircraft is in a hover at 10 ft AGL over the landing point. Notably, the velocity vector has retracted into the aircraft current position point and the acceleration ball surrounds the aircraft current position point indicating zero forward velocity and acceleration, i.e., steady hover. The aircraft is descending from ten feet but at a slower rate than Figure 3B as indicated by the shortened altitude trend tape.

[0054] Advantageously, the system of the present invention uses a unique combination of sensor, navigational and display data enhancing the situational awareness of pilots operating VTOL aircraft while minimizing impact to the pilot's workload.

[0055] It should be appreciated that modifications and variations to the specifically illustrated and discussed structure may be practiced in various embodiments and uses of this invention without departing from the spirit and scope thereof. Such variations may include but are not limited to, substitution of equivalent structure for those shown or discussed and the repositioning of various elements, or the like.

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